BROADBAND POLLING STRUCTURE

FIELD OF THE INVENTION

The present invention relates to antenna structures.

BACKGROUND OF THE INVENTION

Demand for broadband applications employing an increasingly wide range of operable frequencies is growing. These broadband applications have, to date, required antenna structures including a number of independent antenna elements. Each antenna element in such an antenna structure is designated to radiate and/or capture electromagnetic energy within a relatively narrow frequency band from the range of operable frequencies employed. Consequently, a considerable number of antenna elements have been used in broadband applications to radiate and/or capture electromagnetic energy over the entire range of operable frequencies, thereby adding to the size and complexity of the antenna structure.

Various alternatives have been proposed to reduce the size and complexity of antenna structures used in broadband applications. One such alternative being explored is tapered slot antennas. Tapered slot antennas operate (e.g., radiate and/or capture electromagnetic energy) over a frequency spectrum ranging from about 900 MHz to well over 10 GHz. To support this wide range of operative frequencies, a tapered slot antenna includes an expanding slot transmission line formed on a dielectric substrate, thereby creating a balanced impedance. A balanced impedance may be characterized by a pair of conductors, in the presence of a ground, which support the propagation of a balanced signal therethrough. A balanced signal includes a pair of symmetrical signals, which are equal in magnitude and opposite in phase.

While operating over a wide frequency spectrum, tapered slot antennas are known to provide narrow directivity. The directivity of an antenna may be defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. Directivity may also be characterized as the directional beam pattern of the electromagnetic energy radiated and/or captured by an antenna. For example, the directivity of a tapered slot antenna may be characterized as having a cigar-like directional beam pattern.

Tapered slot antennas are endfire-type devices, having a narrow directional beam pattern emanating from the exposed end of the antenna's dielectric substrate. Consequently, tapered slot antennas have been unsuitable for a number of broadband applications, such as in a radio frequency identification ("RFID") polling system, requiring wider directivity than endfire-type devices. For these types of broadband applications, traditional multi-element antenna structures have been used to date.

SUMMARY OF THE INVENTION

I have invented an antenna structure, which operates over a wide frequency spectrum and offers wider directivity than endfire-type devices. I have recognized that the narrow directivity of tapered slot antennas is attributable to the phase velocity supported by antenna's dielectric substrate. In accordance with the present invention, my antenna structure supports a phase velocity greater than the speed of light. In one embodiment of the present invention, an antenna structure comprises a tapered antenna element coupled with a symmetrically shaped ground plane. The tapered antenna element is positioned at an angle from ground plane, which may advantageously be 90 degrees.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be better understood from reading the following description of non-limiting embodiments, with reference to the attached drawings, wherein below:

FIG. 1 is a perspective view of a known antenna structure;

FIG. 2(a) is a perspective view, while **FIG. 2(b)** is a cross-sectional view of an embodiment of the present invention;

FIGS. 3(a) through **3(h)** are side views of examples of a feature of the present invention; and

FIG. 4(a) is a perspective view, while **FIG. 4(b)** is a top view of an example of the present invention.

It should be emphasized that the drawings of the instant application are not to scale but are merely representations and thus are not intended to portray the specific parameters or the structural details of the invention, which may be determined by one of skill in the art by examination of the information contained herein.

DETAILED DESCRIPTION

Tapered slot antennas belong to a class of planar, endfire-type devices commonly referred to as travelling wave antennas. Travelling wave antennas are known to offer a wide operative frequency range (from about 900 MHz to about 90 GHz) and high gain (from about 7 to 10 dB). However, travelling wave antennas also have limited directivity. More particularly, travelling wave antennas demonstrate relatively narrow symmetrical ***E-*** and ***H-*** plane directional beam patterns.

Referring to **FIG. 1**, a perspective view of a known tapered slot antenna **10** is shown. Tapered slot antenna **10** has a balanced configuration, realized by an expanding slotted transmission line. More particularly, tapered slot antenna

10 comprises a first and a second conductive film or leaf, **15** and **20**, formed on a substrate **25**. First and second conductive leaves, **15** and **20**, support the propagation of balanced signals therethrough – i.e., a symmetrical pair of signals which are equal in magnitude and opposite in phase. Moreover, first and second leaves, **15** and **20**, are defined by an expanding tapered slot **30**. Expanding tapered slot **30** exposes the upper surface of substrate **25** and its dielectric characteristics. By this arrangement, tapered slot antenna **10** has a planar, travelling wave design, radiating and/or capturing electromagnetic energy from an exposed end of substrate **25** – i.e., in the direction of the x-axis.

Coupled with tapered slot antenna **10** is an unbalanced impedance **35**. Unbalanced impedance **35** comprises a first conductor for supporting the propagation of unbalanced (i.e., asymmetrical) signals therethrough with respect to a second conductor (i.e., ground). Unbalanced impedance **35** commonly comprises a coaxial cable, though various substitutes and alternatives may also be employed. For the purposes of illustration, unbalanced impedance **35** is coupled with a radio frequency device **40**, such as a receiver, transmitter or transceiver.

Tapered slot antenna **10** couples first and second conductive leaves, **15** and **20**, with unbalanced impedance **35** by means of various means, including a balun (not shown), for example. Alternatives to the balun are disclosed in co-pending patent application, Serial Number 09/836,024, filed on April 17, 2001, commonly assigned with the present invention, hereby incorporated by reference. The balun and these alternatives convert a balanced signal propagating through first and second conductive leaves, **15** and **20**, to an unbalanced signal for unbalanced impedance **35**, and vice versa.

Tapered slot antenna **10** transforms electromagnetic energy from a guided wave into a plane wave propagating through free space. A continuous

interaction between the guided wave and the plane wave may only be maintained if the free space wavelength, λ_0, and the guided wavelength, λ_g, satisfy the following mathematical relationship:

$$\lambda_0 = \lambda_g * \cos\theta$$

where θ is an angle from the *x*- axis in which electromagnetic energy is radiated or captured. The direction of the electromagnetic energy radiated or captured by tapered slot antenna **10** is determined by the Poynting vector, **E** x **H**, which is defined by the electromagnetic field distributions along antenna **10**. The total field may be viewed as a combination of six field components corresponding with the dielectric-to-air interface in tapered slot antenna **10**.

The directivity of tapered slot antenna **10** is affected by the characteristics of substrate **25**. More particularly, the dielectric characteristics of substrate **25** are a function of its geometrical parameters (e.g., length, width and thickness), as well as the taper profile of expanding tapered slot **30**. Consequently, the geometrical parameters and taper profile influence the directivity, and thusly the ***E***- and ***H***- plane directional beam patterns of tapered slot antenna **10**.

Tapered slot antenna **10** may be modeled using the wave phenomenon theory. A wave propagating in a non-dispersive medium may be characterized by the following relationship:

$$k = \omega\sqrt{\mu * \varepsilon} = \omega / v_p$$

where k is the wavenumber, μ is the permeability and ε is the permittivity of the non-dispersive medium, respectively. From the above dispersive

mathematical relationship, a wave propagating in free space may be stated as follows:

$$k_0 = \omega\sqrt{\mu_0 * \varepsilon_0} = \omega/c$$

where k_0 is the wavenumber, μ_0 is the permeability and ε_0 is the permittivity of free space. The directivity of an endfire travelling wave antenna may be derived from the above dispersive equations, and restated by following equation:

$$k = k_0 + \pi/L$$

where L is the length of the endfire travelling wave antenna. This equation forms the basis of the Hansen-Woodyard condition. The Hansen-Woodyard condition has shown that the directivity of an antenna is maximized if the wavenumber, k, satisfies the above equation. According to the Hansen-Woodyard condition, the directivity of the antenna may be increased by slowing the propagation of the wave guided by the radiating structure (e.g., non-dispersive medium). Consequently, the Hansen-Woodyard condition concludes that the directivity of a travelling wave antenna is in the endfire direction (*x*- axis) having a beam pattern of electromagnetic energy with a relatively finer main lobe. It has been experimentally observed that a tapered slot antenna having a length, L, between $4 * \lambda_0$ and $10 * \lambda_0$, where λ_0 is the free space wavelength, and a substrate thickness between $0.003 * \lambda_0$ and $0.01 * \lambda_0$, generally exhibits standard travelling-wave characteristics of broad bandwidth and low side lobe field intensity characteristics. For more information, *see* Lee and Chen, "Advances in Microstrip and Printed Antennas," John Wiley & Sons

1997, pp. 443-513. Since travelling wave antennas have a narrow directivity, it is unsuitable for a number of broadband applications, including radio frequency identification ("RFID") polling systems, for example, which require wider directivity than endfire-type devices, such as tapered slot antenna **10**, to determine the location and status information of a corresponding unit transponder within a large enclosed area.

Referring to **FIGS. 2(a)** and **2(b)**, an embodiment of the present invention is shown. Here, a broadband antenna structure **100** is depicted having wider directivity than tapered slot antenna **10** of **FIG. 1**. Broadband antenna structure **100** supports a phase velocity greater than the speed of light, and comprises an antenna "flag" element **110** for radiating and/or capturing electromagnetic energy over a wide frequency range. Antenna "flag" element **110** comprises a conductor, such as aluminum or copper, for example.

Antenna element **110** has a taper, described in detail hereinbelow in accordance with **FIGS. 3(a)** through **3(h)**. This taper affords broadband antenna structure **100** a wide frequency bandwidth, much like tapered slot antenna **10** of **FIG. 1**. In one example of the present invention, antenna "flag" element **110** has a frequency range of about 900 MHz to about 4 GHz. The taper of antenna "flag" element **110** also affords broadband antenna **100** relatively wider directivity.

Broadband antenna structure **100** also comprises a ground plane **125**. Ground plane **125** comprises a symmetrical shape to support the relatively wider directivity of broadband antenna structure **100**. Advantageously, ground plane **125** has a disk-like shape, though other symmetrical shapes may also be employed in conjunction with the present invention.

Coupled with broadband antenna structure **100** is an unbalanced impedance **135**. Unbalanced impedance **135** comprises a first conductor **115** for supporting the propagation of unbalanced (i.e., asymmetrical) signals

therethrough with respect to a second conductor **120**, which is electrically coupled with ground plane **125**. It should be noted that first conductor **115** also provide mechanical support for antenna "flag" element **110**.

Unbalanced impedance **135** commonly comprises a coaxial cable – particularly with respect to wireless and radio frequency devices. Unbalanced impedance **135**, however, may be realized by various substitutes and alternatives. As shown, unbalanced impedance **135** is coupled with a radio frequency device **140**, such as a receiver, transmitter or transceiver. It will be apparent to skilled artisans upon reviewing the instant disclosure that various alternatives may be employed for coupling broadband antenna structure **100** with radio frequency device **140**, such as those detailed in co-pending patent application, Serial Number 09/836,024, filed on April 17, 2001, commonly assigned with the present invention.

Broadband antenna structure **100** has relatively wider directivity than tapered slot antenna **10** of **FIG. 1**. Tapered slot antenna **10** has a cigar-like directional beam pattern **105(a)** in the *x*-, *y*-, and *z*- directions. Broadband antenna **100** supports side lobes with a butterfly wing-like directional beam pattern **105(b)** in the *x*-, *y*-, and *z*- directions. Butterfly wing-like directional beam pattern **105(b)** is supported by the taper of antenna "flag" element **110** and the symmetrical shape of ground plane **125**. Antenna "flag" element **110** is at an angle, $\phi_{x,y,z}$, with respect to the *x*-, *y*- and *z*- axes. Advantageously, angle, $\phi_{x,y,z}$, is about 90 degrees to support the widest available directivity for broadband antenna structure **100**. Consequently, with the addition of directional beam pattern **105(b)** the directivity of antenna element **110** no longer corresponds with merely endfire-type devices, such as tapered slot antenna **10**.

Referring to **FIG. 3(a)** through **3(h)**, side views of examples of the various tapers available for antenna "flag" element **110** of **FIG. 2(a)** and **2(b)** are shown. With respect to **FIG. 3(a)**, the taper for antenna "flag" element **110** is referred to as a linear constant profile. The taper of **FIG. 3(b)** is referred to as an exponential profile. **FIG. 3(c)** illustrates a taper having an exponential constant profile, while **FIG. 3(d)** depicts a taper having a tangential profile. The taper of **FIG. 3(e)** is commonly referred to as a step-constant profile, while the taper of **FIG. 3(f)** is commonly referred to as parabolic profile. **FIG. 3(g)** illustrates a taper having a broken-linear profile, and **FIG. 3(h)** depicts a taper having a linear profile. Although a number of tapers are illustrated in **FIGS. 3(a)** through **3(h)**, various alternatives apparent to skilled artisans upon reviewing the instant disclosure are also contemplated herein.

The dimensions of each taper principally affect the response characteristics (e.g., frequency range and directivity) of broadband antenna **100**. These dimensions are measured relative to the taper. Consequently, the length of the antenna "flag" element **110**, for example, as well as the width of the deviation from the normal of the antenna "flag" element **110** both affect the response characteristics of broadband antenna structure **100**. Similarly, the contour of the taper chosen also has an influence on the response characteristics of broadband antenna **100**.

Referring to **FIGS. 4(a)** and **4(b)**, an example of the present invention is shown. More particularly, a broadband antenna arrangement **200** is illustrated for providing a sufficiently wide directivity to scan a three- dimensional area. Antenna structures supporting directivities capable of scan three- dimensional space are of interest in polling applications, such as radio frequency identification systems. For example, in a radio frequency identification system, one design would be to place broadband antenna arrangement **200** on top of a ceiling of a large enclosed area to determine the location and status information

of a corresponding unit transponder therein. It will be apparent to skilled artisans, however, upon reviewing the instant disclosure that broadband antenna arrangement **200** may also be useful in various other applications, including radar systems and a number of wireless cellular applications.

Broadband antenna arrangement **200** comprises a ground plane **225**. Ground plane **225** comprises a symmetrical shape to support the relatively wider directivity of broadband antenna arrangement **200**. Advantageously, ground plane **225** has a disk-like shape. Various alternative symmetrical shapes will be apparent to skilled artisans upon reviewing the present disclosure, and may also be employed in conjunction with broadband antenna arrangement **200**.

Broadband antenna arrangement **200** also comprises at least two antenna "flag" elements, **210** and **215**, for radiating and/or capturing electromagnetic energy over a wide frequency range. Each antenna "flag" element is designed with a taper, much like that of antenna "flag" element **110** of **FIG. 2(a)** and **2(b)**. The taper of each antenna "flag" element, **210** and **215**, affords broadband antenna arrangement **200** with a wide frequency bandwidth (e.g., about 900 MHz to about 4 GHz). The taper of each antenna "flag" element, **210** and **215**, also affords broadband antenna arrangement **200** with sufficiently wide directivity to poll and/or scan a three- dimensional space. Depending on the accuracy required for polling and/or scanning such a three- dimensional space, a greater number of antenna "flag" elements (e.g., four or more in total) may be required. Each antenna "flag" element, **210** and **215**, as such, has fast wave antenna characteristics. Consequently, antenna "flag" elements, **210** and **215**, should have a sufficiently close relative proximity with ground plane **225** to cause a fast wave excitation.

Each antenna "flag" element, **210** and **215**, supports a complex directivity. The directivity of each antenna "flag" element comprises a cigar-

like directional beam pattern in the *x*-, *y*-, and *z*- directions. Moreover, each antenna "flag" element, **210** and **215**, supports a butterfly wing-like directional beam pattern (e.g., pattern **105(b)** created by antenna "flag" element **110** of **FIG. 2(a)**) in the *x*-, *y*-, and *z*- directions. By this complex directivity, conical-like directional beam patterns are created by each antenna "flag" element, **210** and **215**, to enable the desired three- dimensional space to be polled and/or scanned. Antenna "flag" elements, **210** and **215**, are each positioned at an angle, $\phi_{x,y,z}$, with respect to the *x*-, *y*- and *z*- axes. Advantageously, the angle, $\phi_{x,y,z}$, of each antenna "flag" element, **210** and **215**, is about 90 degrees to support the widest available directivity for broadband antenna arrangement **200**.

To insure greater coverage for polling and/or scanning a three-dimensional space, a slow wave antenna element **220** may also be incorporated within broadband antenna arrangement **200**. Slow wave antenna element **220** provides a relatively wider directivity than antenna "flag" elements, **210** and **215**, and thusly, may have a narrower frequency range than antenna "flag" elements, **210** and **215**. Slow wave antenna element **220** may be selected from various known designs, such as a dipole, for example. More particularly, antenna element **220** has slow wave characteristics. Consequently, slow wave antenna element **220** should have a sufficiently greater distance to ground plane **225** than antenna "flag" elements, **210** and **215**.

Coupled with broadband antenna arrangement **200** is an unbalanced impedance **235**. Unbalanced impedance **235** comprises a first conductor **234** for supporting the propagation of unbalanced (i.e., asymmetrical) signals therethrough with respect to a second conductor **232**, which is electrically coupled with ground plane **225**. It should be noted that first conductor **234** also provide mechanical support for each antenna "flag" element, **210** and **215**.

Unbalanced impedance **235** commonly comprises a coaxial cable – particularly with respect to wireless and radio frequency devices. Unbalanced impedance **235**, however, may be realized by various substitutes and alternatives. As shown, unbalanced impedance **235** is coupled with a radio frequency device **240**, such as a receiver, transmitter or transceiver. It will be apparent to skilled artisans upon reviewing the instant disclosure that various alternatives may be employed for coupling broadband antenna **100** with radio frequency device **240**, such as those detailed in co-pending patent application, Serial Number 09/836,024, filed on April 17, 2001, commonly assigned with the present invention.

While the particular invention has been described with reference to illustrative embodiments, this description is not meant to be construed in a limiting sense. It is understood that although the present invention has been described, various modifications of the illustrative embodiments, as well as additional embodiments of the invention, will be apparent to one of ordinary skill in the art upon reference to this description without departing from the spirit of the invention, as recited in the claims appended hereto. It is therefore contemplated that the appended claims will cover any such modifications or embodiments as fall within the true scope of the invention.